NRL REPORT 3505

ELECTROMAGNETIC PROBES FOR SUPERSONIC FLAMES

F. M. Gager and G. C. Schleter

June 30, 1949

Approved by:

Dr. R. M. Page, Superintendent, Radio Division III

NAVAL RESEARCH LABORATORY
CAPTAIN F. R. FURTH, USN, DIRECTOR
WASHINGTON, D.C.

DISTRIBUTION

CNO	1
ONR Attn: Code 470	1
CO, USNAD, Dover, N. J.	1
BAGR, CD, Wright-Patterson AFB Attn: CADO-D1	1
OCSigO Attn: Ch. Eng. & Tech. Div., SIGTM-S	1
CO, SCEL Attn: Dir. of Eng.	2
CG, AMC, Wright-Patterson AFB Attn: Eng. Div., Electronics Subdiv., MCREEO-2	1
CO, Watson Labs., AMC, Red Bank Attn: ENR	1
CO, Air Force Cambridge Res. Labs., Attn: ERRS	1
RDB Attn: Library Attn: Navy Secretary	 2 1
ANAF-G/M Mailing List No. ~~9~~ 10 Parts A, C, DG, and DP	

CONTENTS

01
X

ABSTRACT

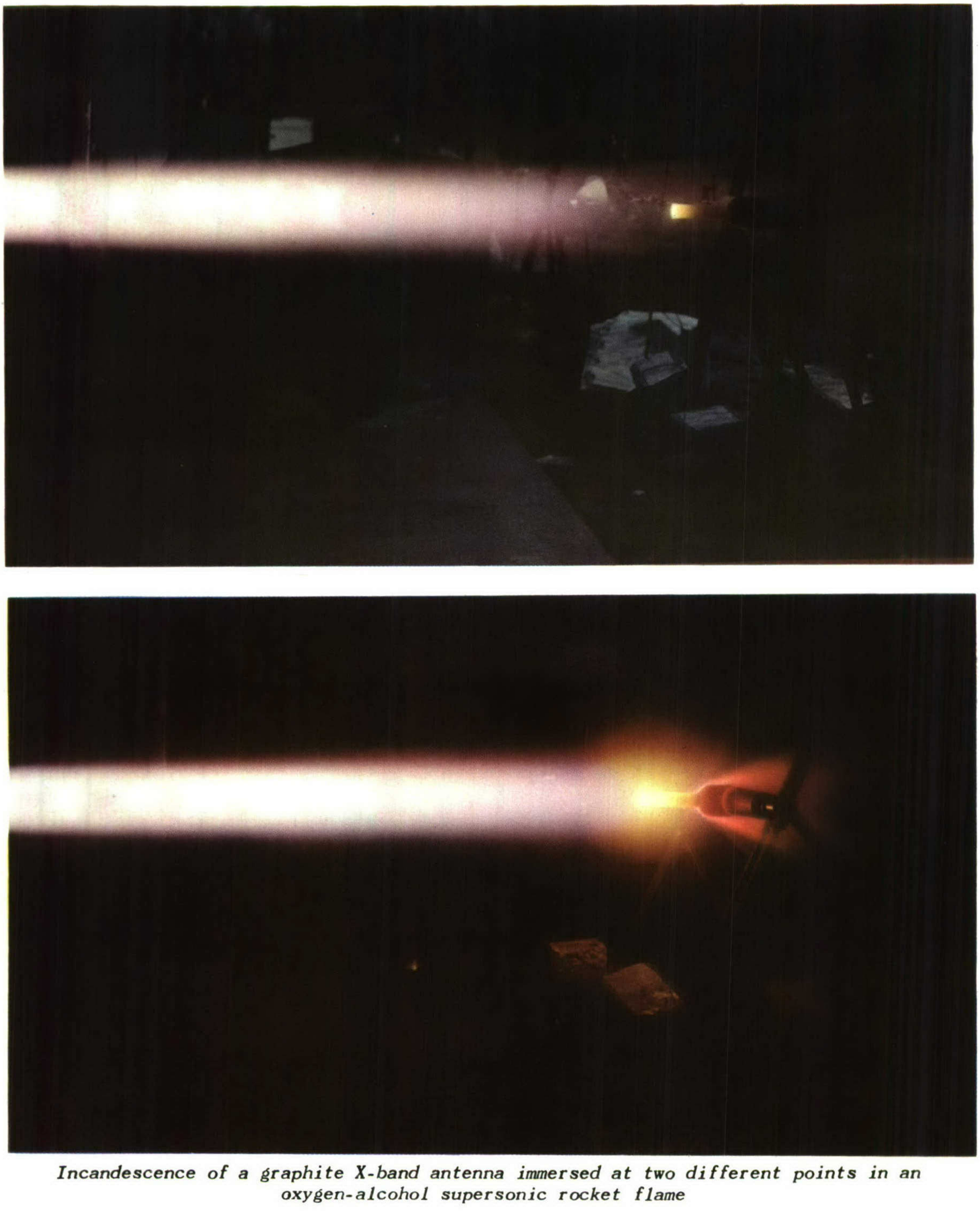
This report details the development of electromagnetic probes for S, X, and K-band insertion loss studies on supersonic flames and of associated automatic VSWR equipment. Evaluation of the life of the probes is set forth, along with information on flame-loading of probes and certain insertion loss data taken with a 1500-lb oxygen-alcohol and a 400-lb acid-aniline motor.

PROBLEM STATUS

This is an interim report on Problem R11-03R, now closed; work is continuing under Problem R11-13R.

AUTHORIZATION

NRL Problem R11-13R



Incandescence of a graphite X-band antenna immersed at two different points in an oxygen-alcohol supersonic rocket flame

ELECTROMAGNETIC PROBES FOR SUPERSONIC FLAMES

INTRODUCTION

The problem of determining the physical nature of insertion loss, or attenuation caused by interposing a flame in an electromagnetic wave propagation path, is difficult because of the number of alternative explanations which satisfy the data. Measurements made by the Naval Research Laboratory, and others, indicate that the interposition of a supersonic flame in both the near- and far-field electromagnetic paths of a transmitter-receiver system changes the propagation. Much information is available from cross-flame and down-flame insertion loss for low- and supersonic-velocity flames, but knowledge as to the temperature, pressure, and velocity distribution within these flames is quite meager. Consequently, the physical nature of the electromagnetic barrier is not established. Because both the radiator and the absorber are situated outside the flame boundary, and because ground effects are present to a degree, one does not always know the proper division of energy or the relative effect of the various phenomena (absorption, diffraction, reflection, etc.) on cross-flame or down-flame propagation studies.

Were suitable in-flame electromagnetic probes available, not only could the transmission path between the radiator and the absorber be supplied with a flame barrier, but also one of the radiators or absorbers or both could be flame-encased. In order to investigate more thoroughly the physical nature of the flame, research on and development of in-flame electromagnetic probes were initiated to clarify the quasi-optical paths traversed by the radiant energy. The problem quite naturally turns to the availability of materials for such probes and the permissible radiator designs which these materials provide. In general, the probes must be able to withstand severe heat shock, very high temperatures, and supersonic eroding velocities, and preferably they should be small with respect to the flame dimensions.

TYPES OF PROBES

If a material is a dielectric and behaves relatively so at elevated temperatures, the rod-type directive-radiator design is applicable to the problem. On the other hand, if a material which is nonconducting at room temperatures becomes conducting at elevated temperatures, the rod-type of probe design is no longer applicable, and the open-guide design becomes appropriate. When a material is initially a conductor at room temperatures, and more or less so at extremely high temperatures, the open-tube or guide-type of radiator design is also in order. In the latter design, where the material is a dielectric, the wall thickness of the tube is an important design parameter; where the material is a conductor, the guide dimensions are more important than the wall thickness.

PROBE MATERIALS

Any investigation of materials suitable for construction of probes of either the rod or open-guide design should take into account relative abundance, mechanical properties such as workability and machineability, and important electrical properties such as dielectric constant and conductivity.

Ceramic Materials

Ceramic materials were investigated first. However, little encouragement was received from those skilled in their manufacture and use. For the most part, the melting points of these materials are below those imposed by the problem. In addition, many have the adverse property of softening long before the melting point is reached, making them subject to severe erosion. Two classes of ceramics were sought, those which maintain their dielectric properties in the neighborhood of their melting points and those which, by comparison, become relatively good conductors at extremely high temperatures. The first class would be suitable for the dielectric rod type radiators, the latter for the open-guide or tube-type radiator design. Most ceramic materials with high melting points fall into the second class, although the literature is very sparce on the properties of many of these materials at high temperatures.

A number of commercial companies[1] were consulted for information on various ceramics for which only meager information is available in the literature. These include MgO, ZrO_2, ThO_2, ThO_2-P_2O_5, BeO-Al_2O_3-ThO_2, BeO-Al_2O_5-ZrO_2, ZrO_2-MgO-Al_2O_3, B_aO-ZrO_2, and SrO-ZrO_2. Of this group, data were available on only ThO_2, MgO, and ZrO_2, all of which have high melting points. Sample tubes of ThO_2, MgO, and ZrO_2 (stabilized) were obtained from the Norton Company, but the dimensions of these tubes were not according to probe-design requirements because the desired thin wall could not be fabricated.[2]

The tubes were arranged with r-f feed sections and measured as open-guide type radiators, and a plot was made of the radiation field patterns. For example, the radiation pattern of the ZrO_2 tube was measured at room temperature; then the tube was heated above red heat with an oxygen-acetylene flame and the pattern was again measured. A plot of the radiation pattern taken at an elevated temperature shows that it approaches the expected radiation pattern of a conducting tube of similar dimensions. An alundum (AL_2O_3) tube, commonly available from chemistry supply houses, was arranged as a dielectric open-guide probe and measured in the same manner as the ZrO_2 tube with similar results. Alundum is a poor conductor of heat, and during these measurements it showed signs of moderate erosion.

Since, for a number of reasons, the available ceramic materials did not look too promising, other compounds (including nitrides, carbides, and tellurides) were examined. The literature contains very little information on tellurides, but some meager data were found for boron nitride and for titanium, tantalum, and hafnium carbides. Correspondence

---

[1] *Lava Crucible Company, Pittsburgh, Pa., c/o Res. Dept.; Lindsey Light and Chemical Company, West Chicago, Ill.; Clifton Products Company, Painsville, Ohio; Norton Company, Worcester, Mass.; Linde Air Products Co., North Tonawanda, N. Y.*

[2] *An improper wall thickness can give rise to multilobed radiation patterns. Although such patterns are not usually desirable, these tubes were considered adequate for the purpose intended.*

was directed to several companies and individuals[3] concerning the electrical properties of tellurides of cadmium, magnesium, and silicon, in particular, and of silicon carbide, boron nitride, and titanium carbide. Information received from Canadian Copper Refinders, Ltd., eliminated serious consideration of tellurides in general because of their excessive brittleness and oxidation at high temperatures, and for similar reasons information received from the Titanium Alloy Mfg. Company eliminated consideration of titanium carbide. Superficially, boron nitride appeared to be a substance which might satisfy the requirements, but the Norton Company indicated they had found no simple method of fabricating the material in the specified sample dimensions.

Conducting Materials

Since most materials believed appropriate for dielectric probes become conductors under the temperature conditions imposed by the problem, conducting materials were also considered for use in the open-guide type of probe design. Among the conducting materials which withstand high temperatures are the carbon products—carbides, nitrides, and carbon itself. Small sample washers of TaC, TiC, ZrN, ZrC, and TaN were obtained from the Norton Company for experimental purposes. In general, carbides are not particularly suitable because of their inability to withstand heat shock, a possible exception being silicon carbide in sintered form. They are also extremely difficult to work, although the Norton Company did well with the samples supplied to the Naval Research Laboratory.

Graphite, a form of carbon, is highly conducting and has a high melting point. In spite of the fact that it is soft and will oxidize, it appears to be an excellent material in a number of ways. A sample graphite probe conducted heat very readily, and the radiation pattern at room and elevated temperature (1300°K+) was substantially the same. From the results of these measurements, it was concluded that electromagnetic probes suitable for S, X, and K-band operation should be designed with this material.

PROBE DESIGN

An electromagnetic probe constructed of graphite cannot rely upon itself for strength. It was decided that the graphite should be built around a steel core so constructed as to allow for ready disassembly and renewal of oxidized portions. The general design of a probe was conceived on this principle for S, X, and K-band use. Figure 1 shows an X-band probe in both assembled and disassembled form, as well as an S-band steel core and partial S-band guide assembly. This figure is sufficient to indicate a uniformity of construction followed in both S and K-band probe parts (not shown). The probe shown has been immersed in flames a number of times and shows some external erosion. It can also be seen from Figure 1 that the hollow steel core design allows waveguide access to the radiator system, providing, in addition, high-temperature protection for both the guide feed and fittings.

The steel-core support used for the X-band probe is also suitable for the K-band design, and therefore some similarity can be seen in the assembled X and K-band probes

---

[3] *Eastman Chemical Company, Rochester, N. Y.; Titanium Alloy Mfg. Company, Niagara Falls, N. Y.; R. T. Vanderbilt Co., 230 Park Ave., N. Y. C.; General Electric Co., Schenectady, N. Y.; American Smelting & Refining Co., Wash., D. C.; M. I. T., Cambridge, Mass., c/o Metallurgy Dept.; National Lead Company, Washington, D. C. office; E. I. Dupont, Wilmington 98, Del. c/o Dev. Div.; The Canadian Copper Refiners, Ltd., Montreal, East P of Q Canada; Foote Mineral Company, Philadelphia, Pa.; Dr. E. C. Henry, Penna. State College, State College, Pa.; Dr. J. Kownig, Rutgers University, New Brunswick, N. J.*

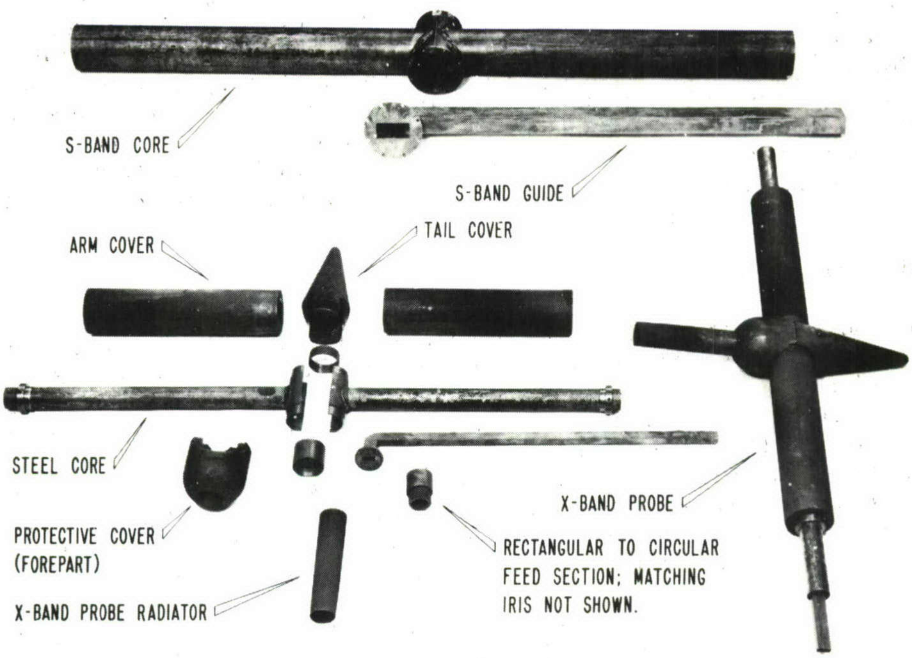


Figure 1 - Electromagnetic probes, assembled and knocked down

shown in Figures 2 and 3. The chief difference between Figures 2 and 3 is that the dimensions of the tube-like, open-guide probes and feed sections conform to the X and K-band design frequencies. These figures also include the general details of mounting and supporting the probes for immersion in the flames. It should also be mentioned that the designs shown in Figures 2 and 3 are flexible enough to allow measurements of open-guide probe sections of different materials, provided the materials can be machined or manufactured to suitable dimensions.

AUTOMATIC VSWR EQUIPMENT

Earlier observations, especially those made in Germany, indicate a detuning of some particular radio radiating systems associated with a missile when the flame was present. A study of the effect of flame-loading on this particular type of electromagnetic probe required automatic voltage standing-wave-ratio equipment so that changes in effective impedance of the probe could be observed. VSWR equipment was designed[4] for all three bands, and the X-band unit was constructed as shown, for example, in Figures 4 and 5. Figure 4 shows a close-up of an inverted slotted section, motor-driven in a sinusoidal fashion through a gear train. This driving motor also rotates a sine potentiometer used

---

[4] *The subject design employs sine potentiometers for the sweep voltage. P. J. Allen (NRL Report R-3110, "A Dynamic Standing Wave Indicator," June 1947, Unclassified) has described the use of linear resistors and sliding contacts operating from the reciprocating probe to accomplish the sweep function.*

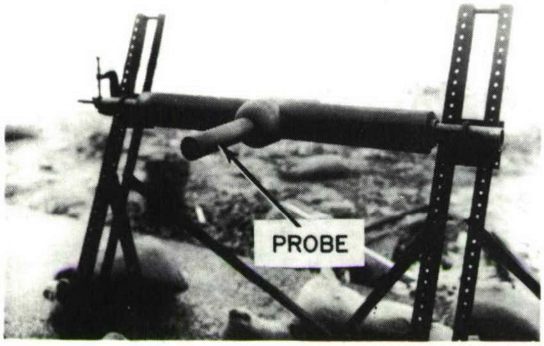


Figure 2 - X-band electromagnetic probe showing method of support

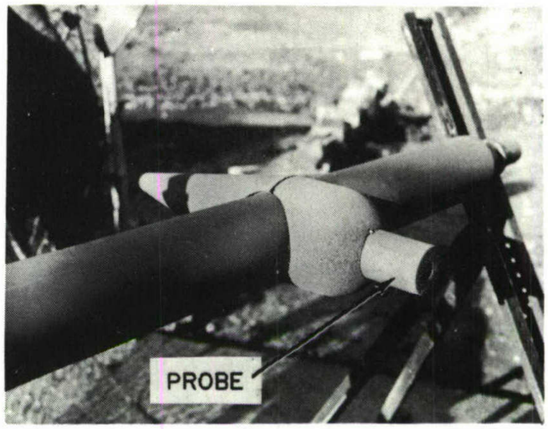


Figure 3 - K-band probe showing method of support

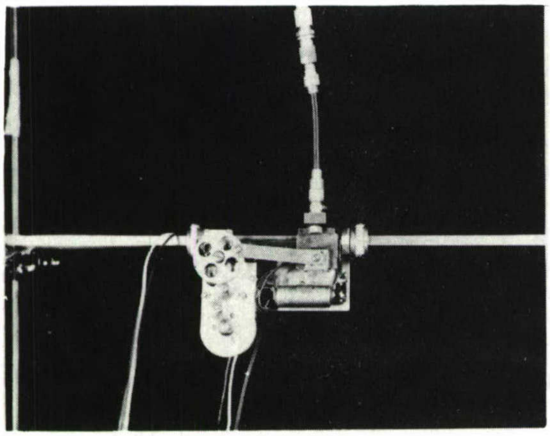


Figure 4 - X-band automatic VSWR equipment

Figure 5 - VSWR and probe equipment on measurement location

to provide sweep voltage for cathode-ray viewing of the voltage standing wave envelope. Figure 5 shows the proximity of the automatic voltage standing wave equipment to the eletromagnetic probe when the latter is set up for in-flame use. A thin mica window (not visible) is located between the slotted line and the probe to maintain clean guide conditions. Figure 5 also shows the motor-driven slotted section being heated by a photo flood lamp, a practice dictated by weather conditions in the field at the time the photograph was taken.

EVALUATION OF IN-FLAME PROBES AND AUTOMATIC VSWR EQUIPMENT

Contractual arrangements for the motor-firing facilities of Reaction Motors Incorporated, Lake Denmark (Dover), New Jersey, and the cooperation of the Power Plant Division, BuAer, who provided the motors, allowed field evaluation of the in-flame probes. Figures 6 and 7

UNCLASSIFIED

Figure 6 - 1500-lb oxygen-alcohol motor-firing facilities

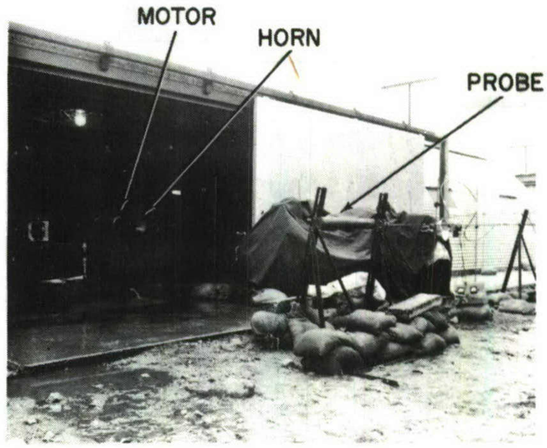


Figure 7 - Close-up of 1500-lb oxygen-alcohol motor-firing facilities with electromagnetic probe in place

show the general layout of the motor-firing range facilities, including an indication of the necessary line and waveguide runs required between the transmitting and receiving equipment and the electromagnetic probe and automatic VSWR equipment. In Figure 6 it can be seen that the X-band electromagnetic probe is positioned before the motor exhaust exit so as to be flame-encased. In Figure 7, a close-up of the motor area shown in Figure 6, the rectangular electromagnetic pick-up horn can be seen to the right of the throat of the 1500-lb-thrust oxygen-alcohol motor. All transmitting, receiving, and recording equipment necessary for observing changes in the transmission path and VSWR of the in-flame probe were installed in the motor control room situated in the right-hand end of the motor test cell (Figure 7).

Exploratory measurements were made at both X and K-band frequencies in order to determine the life and the flame-loading of the probes. These two frequency measurements were conducted with the electromagnetic probe situated at different distances from the motor throat, along the axis of the flame, both outside and inside the visible portion of the flame, and on a 400-lb-thrust acid-aniline motor as well as on the oxygen-alcohol motor mentioned previously.

Experimental Arrangement

With Figures 6 and 7 in mind, reference is made to Figures 8 and 9 which display plan views indicating various positions of the in-flame probe with respect to the flame and the horn link of the electromagnetic path. For each position of the in-flame probe, data were taken (flame-on, flame-off) first with the in-flame probe as a radiator and the electromagnetic horn as an absorber and then vice versa for both X and K-band frequencies. Figure 10 is a block diagram of representative experimental equipment used to obtain the data. The indicated output at the terminals of the absorber was observed without the flame, and then the motor was fired and output indications were recorded as a function of time. While these propagation data were being observed, the voltage standing wave envelope was photographed from an oscilloscope screen.

XPR RUN No.	DIST. "D"	POSITION
1	12'-8"	A OUTSIDE VISIBLE PORTION OF FLAME.
2	12'-8"	
3	12'-8"	
4	12'-8"	
5	12'-8"	
* 6	10'-7$\frac{1}{8}$"	
7	10'-7$\frac{1}{8}$"	B APPROXIMATELY AT VISIBLE TIP OF FLAME.
8	10'-7$\frac{1}{8}$"	
9	10'-7$\frac{1}{8}$"	
10	10'-7$\frac{1}{8}$"	
11	9'-2$\frac{1}{8}$"	C WELL INSIDE FLAME.
12	9'-2$\frac{1}{8}$"	
13	9'-2$\frac{1}{8}$"	

* MOTOR ℄, CARBON ANT. ℄, AND HORN ANT. ℄ NOT IN SAME HORIZONTAL PLANE.

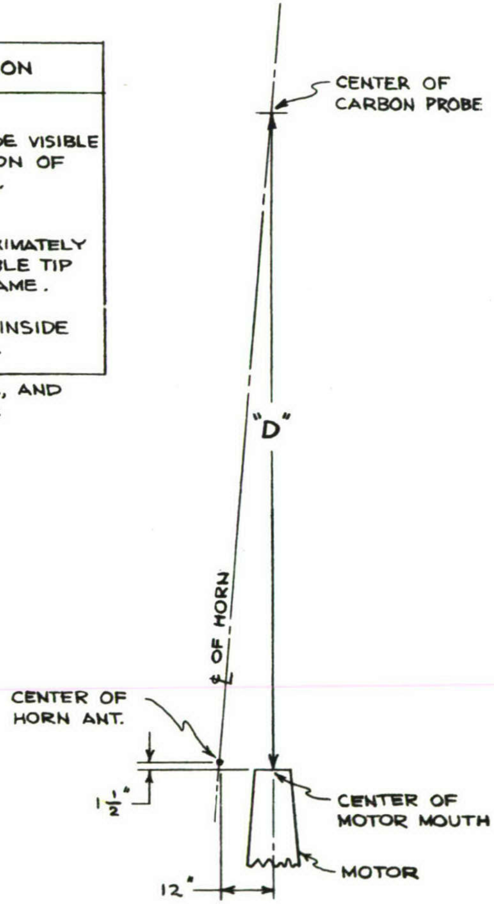


Figure 8 - Plan view of probe positions, 1500-lb oxygen-alcohol motor

XPR RUN No.	DIST. "D"	POSITION
15	12'-3"	G OUTSIDE VISIBLE PORTION OF FLAME.
16	12'-3"	
17	8'-4$\frac{5}{8}$"	H APPROXIMATELY AT VISIBLE TIP OF FLAME.
18	8'-4$\frac{5}{8}$"	
19	8'-4$\frac{5}{8}$"	
20	8'-4$\frac{5}{8}$"	
21	4'-11$\frac{1}{2}$"	I WELL INSIDE FLAME.
22	4'-11$\frac{1}{2}$"	

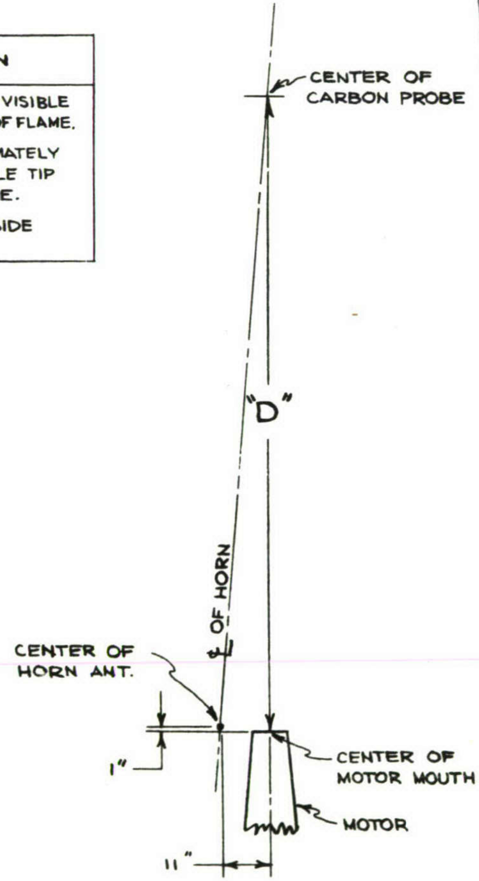


Figure 9 - Plan view of probe positions, 400-lb acid-aniline motor

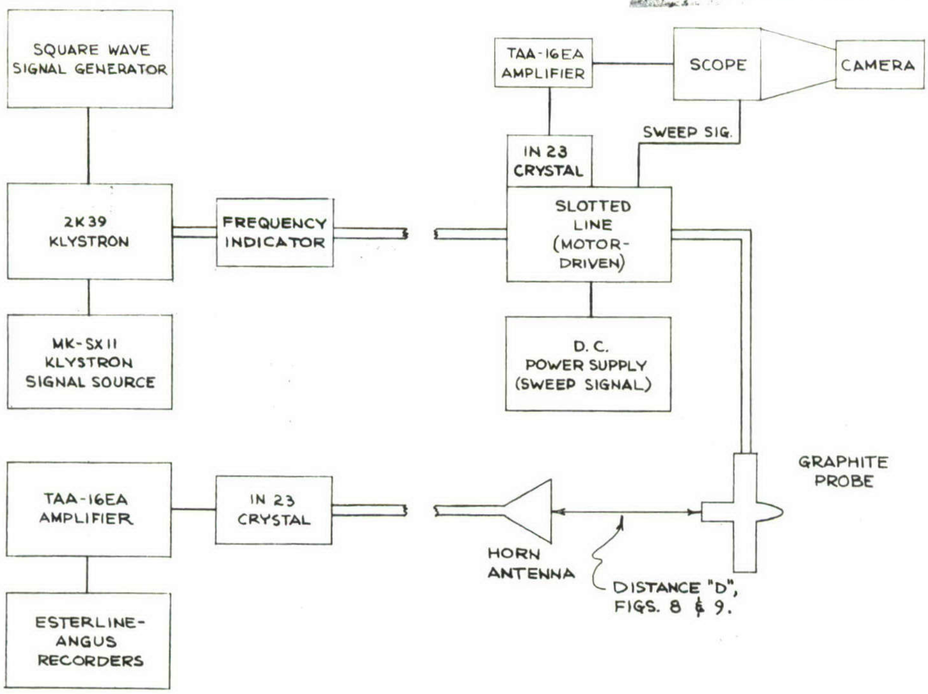


Figure 10 - Block diagram of experimental equipment, X-band

Life of Probes

Although a 10-second life expectancy of any probe material is sufficient to obtain suitable propagation data by the methods employed, it is too short both from the standpoint of obtaining many data as well as of requiring a large number of probe members. When the initial in-flame probe experiments were performed, it was not known how long the probes might last. As it turned out, the X and K-band graphite probes exhibited excellent life, even though they reached white heat (clearly visible in the frontispiece) and continued to burn with a blue glow after the motor was shut off. Several readings of the probe temperature were made with a portable optical pyrometer a short time after the motor was shut off and the fuel tanks were vented of nitrogen pressurizing gas. Some of these readings were as high as 1700°K after a run where the probe was well immersed in the flame.

The X and K-band graphite probes were repeatedly subjected to the flame of a 1500-lb-thrust oxygen-alcohol motor and of a 400-lb-thrust mixed acid-aniline motor, as shown by the frontispiece and in Figures 11, 12, and 13 where the probe takes a flame-trail, flame-tip, and in-flame position successively. Quantitative data on both X and K-band frequencies were taken. However, because of excessive deposits of soot in the probe and guide, little reliability can be attached to the acid-aniline propagation data where the probe was immersed in the flame. It is believed, judging from these measurements, that the probe temperature was higher than that resulting from the oxygen-alcohol flame because thin mica gaskets, located in the guide between the probe and the automatic VSWR equipment, were burned open on several occasions, the entire guide was filled with soot, and a considerable amount of soot was ejected from the slotted sections.

Figure 11 - K-band firing, probe outside visible portion of flame, 400-lb acid-aniline motor

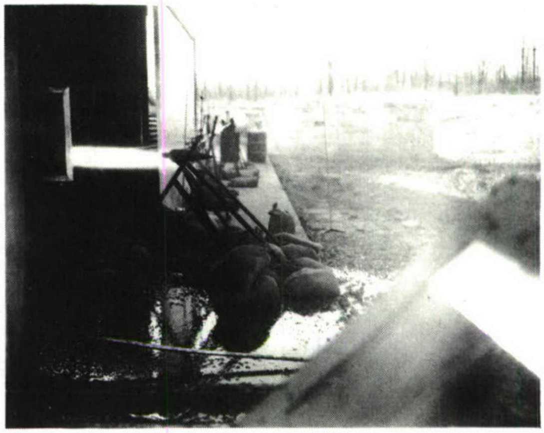


Figure 12 - K-band firing, probe near tip of visible flame, 400-lb acid-aniline motor

Results when the K-band graphite probes were subjected to the flame of a 1500-lb-thrust oxygen-alcohol motor appeared similar to those of the X-band graphite probes. Figure 14 shows an X-band probe after a number of runs, and erosion, both external and internal, is evident by a sharpening of the leading end and standing-wave-like internal erosion.

Figure 13 - K-band firing, probe well within flame, 400-lb acid-aniline motor

After the life expectancy of the graphite probes had been determined, an X-band silicon carbide probe was mounted for flame immersion. Figure 15 shows this probe in the course of being connected for an in-flame run with a 1500-lb oxygen-alcohol motor, and Figure 16 shows all that remained of it after a 30-second run. Silicon carbide has poor heat-shock properties, and during the firing the probe was observed to disintegrate piece by piece. The pieces were extremely hot, and some were blown 125 feet or more into the woods, where they started brush fires. Careful preheating of this material probably would have conditioned it for a successful run, but this procedure would be an added burden with no particular benefits attached. This experience is perhaps representative, however, of what would take place with any material exhibiting poor heat-shock properties.

EXPERIMENTAL INSERTION-LOSS DATA

X-Band, 1500-lb Oxygen-Alcohol Motor

Figure 8 is the probe position diagram with an oxygen-alcohol motor arrangement where, except for one run (No. 6), the center lines of the flame, probe, and rectangular

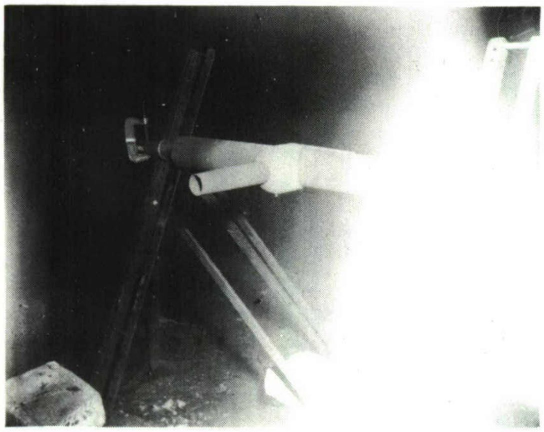


Figure 14 - X-band graphite electromagnetic probe after numerous firings

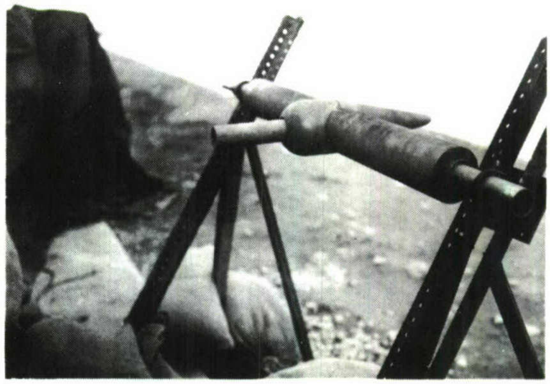


Figure 15 - X-band silicon carbide electromagnetic probe

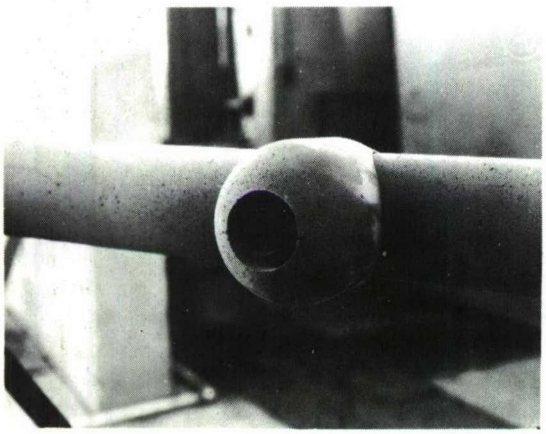


Figure 16 - X-band silicon carbide electromagnetic probe after 30-second firing in oxygen-alcohol flame

horn were all in a horizontal plane. Run No. 6 was an evaluation of the system when propagation was directed mainly at the rectangular horn so as not to pass through the flame. In this position, no propagation change was noted in the 9500-Mc received signal when the flame was present. It is noted that the table in Figure 8 shows six runs made in position A, where the probe is well outside the visible portion of the flame. Runs Nos. 1 and 2 were made with the electromagnetic probe as the emitter and the rectangular horn as the receptor. The average insertion loss due to the interposition of the flame on these two runs was observed to be about 7 db at approximately 9500 Mc. Runs Nos. 3, 4, and 5 were made with the radiator and receptor function reversed. The average insertion loss recorded for these runs was 7.5 db. No particular significance should be attached to the 0.5-db difference on these reciprocity measurements because 0.5 db is within the range of the run-to-run variation. The 7-db figure is not without ground effect, and a quantitative knowledge of redistribution or absorption of energy is lacking. The propagation magnitude change is, however, sizeable.

The electromagnetic probe was moved to position B (Figure 8) with the probe located approximately at the tip of the visible portion of flame. With the probe employed as the emitter, the average insertion loss was found to be approximately 20 db, with the minimum insertion 15 db. When the electromagnetic probe was employed as the receptor, the insertion loss was found to be approximately 13 db. The difference between the 13-db and 20-db average figures is not considered significant, the run-to-run variation being within this range. It should also be noted that where 25 db was recorded on one run, considerable

raw alcohol fuel was found in the guide because of a slow start of the motor. Thus, in position B, it is felt that 15 db is a representative figure for all runs, with the admission that this too is a sizeable magnitude change, whatever the cause.

The electromagnetic probe was then placed well within the flame at position C (see Figure 8 and the frontispiece), and the probe was used alternately as emitter and receptor. The insertion loss observed in this position was above 40 db, regardless of which element was employed as the emitter.

X-Band, 400-lb Acid-Aniline Motor

Reference is now made to Figure 9, the probe plan position with the acid-aniline motor. Runs Nos. 15 and 16, made at position G with the probe outside the visible portion of the flame, constituted a reciprocity check at a frequency of approximately 9550 Mc. With the electromagnetic probe as emitter or receptor, little or no change (0.16 db) was observed when the motor was fired.

When the electromagnetic probe was placed in position H near the visible tip of the flame (Figure 9), the recorded initial insertion loss ran from 0.06 to 0.25 db (essentially no change). This position caused considerable soot to enter the probe and to deposit in the guide, and it was necessary to blow it out from run-to-run with compressed nitrogen gas. If the soot was not removed after a run, the insertion loss observed in the succeeding run was the 0.25 db expressed above.

With the electromagnetic probe well within the flame in position I (Figure 9), no quantitative data could be obtained because of the very rapid fouling of the guide with carbon black. In addition, this position turned out to be an extremely hot one. The mica gasket in the guide, located just before the automatic VSWR equipment, burned out; the hard soldered guide junction, just back of the rectangular-to-circular feed but within the steel core, melted away; and soot and combustion products followed the guide into the control room where quantities were expelled through a slotted section. The only data available for runs Nos. 21 and 22 is the gradual increase of the VSWR from 1.29 to 4.8+ during the first portion of run No. 22. This is explained by the soot-filled guide condition found to obtain after the run. Run No. 21 resulted in melted-off guide fittings within the steel core just back of the antenna, and this necessitated replacement of parts.

VSWR EXPERIMENTAL DATA

X-Band (9500 Mc)

While the propagation data were being obtained, observations of the change in voltage standing wave ratio were made with the aid of the main equipment (Figure 4), and the necessary auxiliary apparatus (Figure 10). With the 1500-lb-thrust oxygen-alcohol motor, the X-band voltage standing wave ratio change at position A (Figure 8) was substantially negligible. In positions B and C (Figure 8), the maximum change noted on any X-band run was approximately ten percent. With the 400-lb acid-aniline motor and the electromagnetic probe in positions G and H (Figure 9), the maximum change noted was also in the neighborhood of ten percent. It might be mentioned that this change is certainly due in part to soot deposits or raw fuel fouling. In positions H and I (Figure 9), the soot conditions did not allow the collection of accurate data.

K-Band (24,000 Mc)

The K-band propagation data, taken with the electromagnetic probes in both flames, were re-evaluated, as were those for X-band, by setting up the equipment at NRL after

field use. Trouble developed in the K-band equipment, and rather than assume the difficulty to be nonexistent at the time the propagation data were taken, it is conservative to designate the propagation data as "suspect." However, reliance may be placed upon the K-band voltage standing wave ratio data.

Accordingly, with the K-band electromagnetic probe positioned at A (Figure 8) in front of the 1500-lb-thrust oxygen-alcohol motor, three runs showed that the voltage standing wave ratio changed little (approximately ten percent). With the probe at positions B and C (Figure 8), a similar change was observed.

When the probe was placed in positions G, H, and I (Figure 9) before the flame of the 400-lb-thrust acid-aniline motor, the voltage standing wave ratio changed only 20 percent from unity, much of this change being due to contamination by carbon particles. The opening in the K-band probe is physically smaller than that in the corresponding X-band probe. Thus, contamination hurled at these probes would affect K-band more than X-band.

FUTURE PLANS

The in-flame probe is not in itself considered sufficient to supply all the technical information required to determine the physical nature of the flame. However, apart from the fact that an in-flame antenna is now considered practical for measurement or other purposes, it is emphasized that the magnitude of probe impedance change at X and K-band caused by the flames was of secondary order. Interpretation of these results could lead to a definite statement that the core of the flame was an absorbing medium, if it were known definitely that none of the energy was reflected from mach nodes or the motor throat and radiated on a broad pattern back over the probe. Instrumentation to determine the existence of the latter is part of future planning.

The flames usually encountered are not large compared with the size of the probes. Therefore, disturbance of a flame by an S, X, or K-band probe of the type described is a foregone conclusion, although the presence of the probe does not change the thrust nor limit the usefulness of the probe in providing contributory evidence on the physical nature of flames. With this in mind, it is planned to construct several S-band probes so that S, X, and K-band probes will be available for future field studies. In addition, it is planned to make cross-shot measurements with both an emitter and receptor probe immersed in a flame. This is to be accomplished by inserting the probes in a dragging rather than a right-angle position, with the radiating end of the probe cut at an acute angle to the axis of the probe to throw radiation off the probe axis.

CONCLUSIONS

In accordance with the life study and electromagnetic propagation experiments with the probes discussed in this report, the following conclusions are made:

1. The X and K-band designs for in-flame probes constructed with graphite on a steel core are satisfactory, and although the S-band design was not evaluated, it is presumably adequate also.

2. Flame-loading of the open-guide type of probe in the immersed positions was observed to be of secondary order at spot X and K-band frequencies.

3. The various values of insertion loss noted for X-band propagation vs probe position within the flame indicate that, when the probe is well within the flame, the insertion loss is greater the nearer the probe is to the pick-up horn. Although ground effect was not the same for all probe positions noted, the data indicate that the flame may act as an absorbing medium or as a confining medium where energy may be partially reflected from mach nodes or the throat of the motor and spread away rather broadly back over the probe.

4. The recovery to normal signal after stopping the motors was immediate; and electron emission from the probe and afterburning of the probe, both internal and external, had negligible effect on the probe field pattern and its voltage standing wave ratio.

ACKNOWLEDGMENT

The authors acknowledge the assistance of their colleagues—Messrs. H. M. Bryant, F. E. Wyman, F. E. Boyd, W. W. Balwanz, R. W. McLendon and T. R. Foust—who accompanied the party which took these and related data on a field trip to Reaction Motors Incorporated, Lake Denmark (Dover), New Jersey, during December 1948. In particular, the efforts of Messrs. W. W. Balwanz and D. L. Fye are acknowledged for their work in determining the db equivalents of the insertion loss data and for rechecking the reliability of the field equipment after transportation back to the Naval Research Laboratory.

* * *